

Slag-Metal Reactions during Welding: Part I. Evaluation and Reassessment of Existing Theories

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A critical review of current thermodynamic theories of slag-metal reactions is presented. A series of preliminary experiments indicates that the previously proposed droplet theory is incorrect and the primary reactions controlling Mn, Si, and Cr content occur in the weld pool. In addition, these experiments show that the net transfer of oxygen is independent of the transfer of Mn and Si.

I. INTRODUCTION

DURING submerged arc welding (SAW), as in other flux-shielded processes, chemical reactions take place between the slag and the metal. This interaction results in compositional changes affecting the structure and properties of the weldment and hence is of considerable practical importance. In order to control the mechanical properties of the weld metal and to match them with those of the workpiece, it is desirable to estimate the extent of interaction between the slag and the metal. Although several researchers have studied this interaction over the last two decades, thus far no general method for determining weld metal composition is available. Empirical equations developed from laborious experiments have been used to predict weld chemistry for specific welding consumables under narrow ranges of welding conditions, and more scientific approaches have given, at best, only a qualitative explanation of the changes occurring in weld chemistry.

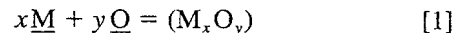
The present work aims at establishing a quantitative relationship between the composition of welding consumables used, the welding parameters employed, and the resulting weld metal chemistry. The work differs from many investigations of the past in that it incorporates fundamental principles of chemical metallurgy and solidification processing while at the same time incorporating many of the more practical features of the SAW process.

The work is presented in three parts. In Part I, the work done by previous investigators is reviewed, and the strengths and shortcomings of prevailing theories are described along with preliminary experiments which prove or disprove certain hypotheses. This critical review, although somewhat lengthy, is necessary to set the stage for the theory and experiments which follow. In Part II,^[35] an entirely new theory is presented to explain the changes in weld chemistry, and a kinetic model is formulated to predict weld metal composition. Finally, Part III^[34] presents the verification of the theory through several different experiments. In addition, the theory has been

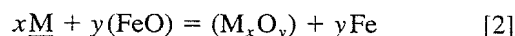
successfully tested by applying it to numerous data published by previous investigators.

II. ANALYSES BASED ON METALLURGICAL THERMODYNAMICS

Most previous researchers of slag-metal reactions during welding have used only thermodynamic considerations in their analyses^[1-15] and have considered reactions such as



and



The equilibrium constants for the above two reactions are

$$K_1 = \frac{(a_{\text{M}_x\text{O}_y})}{[a_{\text{M}}]^x [a_{\text{O}}]^y} \quad [3]$$

$$K_2 = \frac{(a_{\text{M}_x\text{O}_y})}{[a_{\text{M}}]^x [a_{\text{FeO}}]^y} \quad [4]$$

By determining the chemical composition of the weld metal and the slag, researchers have computed mass action indices for Eqs. [1] and [2]. If one assumes that an "effective reaction temperature" (also called "effective equilibrium temperature" or pseudo-equilibrium temperature) is attained during welding, these mass action indices may be related to the equilibrium constants K_1 and K_2 . In this way, a set of effective reaction temperatures may be obtained. A summary of such studies is shown in Table I. Based on these results, some researchers^[1-5] concluded that equilibrium was attained, and others^[6-9] maintained that the slag and metal did not reach equilibrium. In addition to the different conclusions drawn by different researchers (Table I), these purely thermodynamic analyses have two very serious shortcomings:

- (1) They do not take account of the initial compositions of the electrode and the baseplate, though these are as important as flux chemistry in determining final weld metal composition. (The usually small change in slag composition during welding cannot explain the strong influence of electrode and baseplate compositions.)
- (2) These analyses do not take into account the influence of welding parameters, such as welding voltage, current, and travel speed, although the effect of these parameters on weld chemistry is significant, as shown in Table II.

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Table I. Values of the Effective Reaction Temperature Obtained by Different Investigators

Investigator	Effective Reaction Temperature Range
Belton <i>et al.</i> ^[1]	1930 °C to 2030 °C
Christensen ^[2]	1800 °C to 2100 °C
Davis and Bailey ^[4]	1600 °C to 1650 °C
Potapov <i>et al.</i> ^[5]	1900 °C to 2400 °C
Van Bemst ^[6]	1500 °C to 2400 °C
Mitra and Eagar ^[7]	1700 °C to 2000 °C
Chai ^[8]	1800 °C to 2100 °C
North ^[9]	1700 °C to 2400 °C
Lau ^[19]	1680 °C to 3130 °C

Table II. Weld Metal Chemistry Variations Observed on Changing the Welding Process Parameters for Two Types of Fluxes^[17]

Element	Flux Type	
	Manganese Silicate (Pct)	Calcium Silicate (Pct)
C	0.05 to 0.15	0.07 to 0.16
Mn	1.03 to 1.28	0.58 to 1.09
Si	0.33 to 0.92	0.11 to 0.44
O	0.067 to 0.174	0.021 to 0.058

Besides the above two factors, most analyses based on metallurgical thermochemistry do not distinguish between the dependent and the independent variables.^[10] For example, if Eq. [3] is used, then the amount of alloying element M (dependent variable) may be determined only if the oxygen concentration (independent variable) is known. Consequently, in view of these shortcomings, any analysis based solely on metallurgical thermochemistry cannot provide a prediction of weld metal composition with general utility.

A. Analyses Based on More Complex Thermodynamic Models

Some researchers have tried to apply the ionic theory of slags^[11] to examine slag-metal equilibrium during SAW.^[4,12] However, many welding fluxes are acidic, and the silica present in them need not exist only as $(\text{SiO}_4)^{4-}$ ions as these investigators propose. This makes it difficult to calculate the concentration of oxygen (O^{2-}) and other ions which may be present. Moreover, the mere use of the ionic theory does not eliminate the shortcomings of any analysis based solely on thermochemistry as mentioned earlier. Kokh^[13,14] has proposed a more complicated thermodynamic model which considers electrode composition as well as flux composition in determining weld chemistry. However, this model makes use of empirically introduced "retardation" factors, the values of which are unknown *a priori*, and the lengthy procedure of the analysis requires either the use of a computer or several graphic steps.

B. The Neutral Point Concept

Recently, Chai and Eagar^[15] carried out an extensive study of slag-metal reactions during SAW of steel. They

discovered that for each flux, there exists a neutral point (or effective equilibrium point) at which no transfer of alloying element between the slag and the metal occurs. However, this neutral point was not normally reached during the welding process, and the final deviation from this point was dependent on kinetic (*i.e.*, process) factors. The neutral point itself was independent of these process factors. These investigators also formulated a thermodynamic model capable of predicting the neutral point. Their model was based on the following assumptions:

- (1) The effective temperature of chemical reactions in the weld pool is $2000 \text{ °C} \pm 100 \text{ °C}$.
- (2) An empirical relationship exists between the basicity index of the welding flux and the weld metal oxygen content (shown in Figure 1).
- (3) The activity of the components of welding slags may be determined by extrapolating steelmaking data from 1600 °C to 2000 °C by assuming regular solution behavior.
- (4) The primary reactions of interest are those involving silicon, manganese, and oxygen.

Of these, the second assumption is noteworthy in that it implies that the transfer of oxygen is independent of the transfer of other alloying elements. Eagar has suggested earlier^[16] that the high amounts of oxygen obtained in submerged arc weld deposits may be due to the oxygen present in the arc plasma, resulting from the decomposition of the oxides present in the slag to suboxides and oxygen. For most welding fluxes, this oxygen potential is controlled by the silica content of the flux. Results of later work by Chai and Eagar^[18] and more recently by Lau^[19] appear to support this mechanism of oxygen transfer; however, another study was shown that the relationship shown in Figure 1 breaks down in low-silica activity fluxes.^[32]

Figure 2 illustrates the existence of the neutral point postulated by Chai and Eagar.^[15] The figure shows the neutral point for manganese. Neutral points have also been shown to exist for silicon and several other alloying elements.^[7,15,25] Figure 2 also illustrates the dependence of final weld metal chemistry on the initial electrode and baseplate compositions; however, in their analysis, Chai

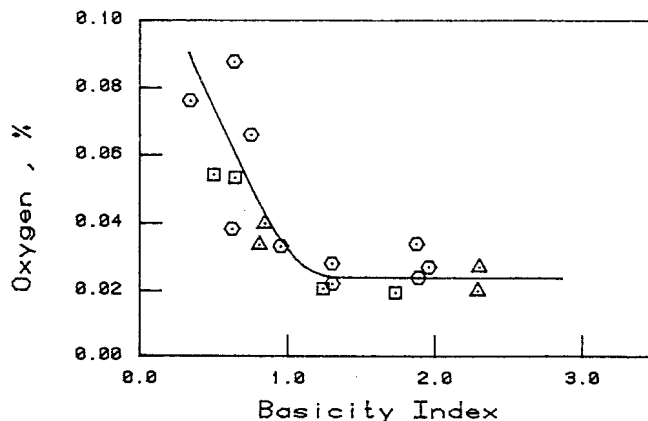


Fig. 1—The empirical relationship between the weld metal oxygen and the flux basicity index.

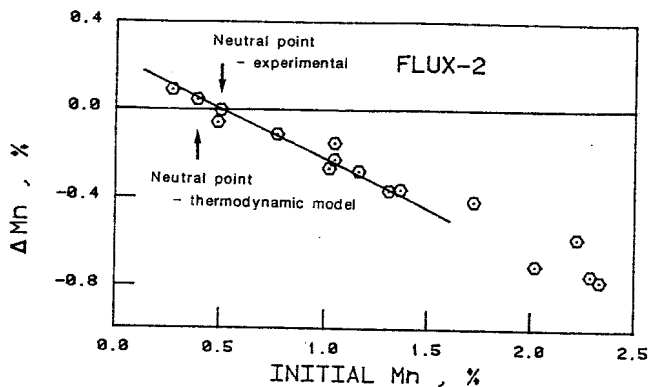


Fig. 2—Results from work by Chai and Eagar indicating the existence of a neutral point.^[15] The initial manganese is a weighted average of the baseplate and the electrode manganese contents calculated from the dilution factor of the weld pool. The change in manganese is the variation of the final manganese content from this initial manganese value.

and Eagar did not explain how or why the welding process factors controlled the kinetics of slag-metal reactions. Nonetheless, they recognized that the compositions of the welding consumables exert a thermodynamic control over weld metal chemistry, while the welding process parameters have a kinetic control over the extent of the reactions.

III. EFFECT OF WELDING PROCESS PARAMETERS ON WELD METAL COMPOSITION

Many investigators have studied the effect of welding parameters on weld metal composition,^[1,9,12,19-26] and all of them have concluded that these parameters have a very significant influence on weld metal chemistry. However, as yet, no quantitative theory has been proposed which takes the effect of these parameters into account and successfully predicts weld metal composition.

Frumin^[20] was the first researcher to investigate the influence of welding voltage and current on weld metal chemical composition. He found that the transfer of alloying elements between slag and metal increases with increasing voltage and decreases with increasing current. He explained this phenomenon by considering SAW as a process where the electrode melts and the molten droplets pass through a slag layer and settle into the pool. However, his analysis ignores the existence of an arc cavity and the possibility of reactions occurring at the slag-metal interface in the weld pool.

Christensen^[2] also studied the effect of welding conditions on weld metal chemistry. He concluded that the effect of these parameters on weld metal chemistry was less than that due to variations in welding consumables. He classified fluxes into three types: (1) manganese silicate, (2) calcium silicate, and (3) basic. For each flux, he characterized the amount of Mn, Si, and O transfer by two variables, namely, (a) the initial or nominal manganese content (the nominal manganese content is the manganese content expected by mere fusion of electrode and baseplate in the absence of chemical reactions) and (b) an operational parameter (n) which is a product of

voltage (V), current (I), and travel speed (v). Although the use of the above two variables is mainly empirical in that there is no quantitative relationship between these variables and weld composition, Christensen's work provides some useful ideas about the extent of alloy transfer in different fluxes.

IV. THE DROPLET-REACTION TIME THEORIES

Many researchers have suggested that slag-metal reactions and the transfer of alloying elements take place inside the arc column.^[9,21-27] Pokhodnya^[21] and Pokhodnya and Kostenko^[22] suggested that the kinetics of these reactions were governed by the "relative reaction time" of the droplets at the electrode tip. In their model, current is the main factor controlling relative reaction time and, consequently, the kinetics of the reactions, whereas voltage has a much smaller effect. Although their results show relationships between relative reaction time and current and voltage, they did not conduct experiments to determine the direct effect of changes in the relative reaction time of the droplets on weld metal chemistry in the absence of any change in the welding parameters, nor did they actually collect the electrode tips and analyze them. Recent work by Lau,^[19] who actually collected and analyzed electrode tips and the droplets after they passed through the arc, shows that current does not control the chemical composition of the droplets either at the electrode tip or after they pass through the arc. North^[9] made multilayer welds (ten-high pads) using a 1.85 to 1.93 pct manganese electrode and an acid calcium silicate flux (65 pct SiO₂-35 pct CaO) under different welding conditions. His results indicated that increasing the voltage increased the amount of manganese lost to the slag, whereas increases in current had the opposite effect. He explained this by suggesting that these parameters controlled the time of reaction between the droplet and the slag either at the electrode tip or as the drop transfers through the arc cavity. In order to prove this mechanism of alloy transfer, he collected the droplets using a rotating water-cooled anode and analyzed them with an electron microprobe. Although his results indicated that the effect of current and voltage on the composition of the droplets is similar to the effect of these parameters on the composition of the weld metal, there is a very wide variation between the droplet composition and that of the top weld of the ten-high pad made under identical welding conditions, as shown in Figure 3. According to the droplet theory, the composition of both the droplet and the top multiple-pass weld bead should be the same.

Other proponents of the droplet theory have argued that it is not possible to have any quantitative theory based on the droplet-reaction time mechanism^[23,29] and have suggested the use of empirical equations.^[23-27]

Thier^[25,26,27] has proposed empirical equations for computing the alloy content of the weld metal. These equations contain as many as six empirical constants which vary for different fluxes and which must be determined by regression analysis of experimental data for each flux. Potapov and Lyubavski^[23,24] have proposed a simpler empirical equation, again based on regression analysis, but the use of this equation is limited to the transfer of

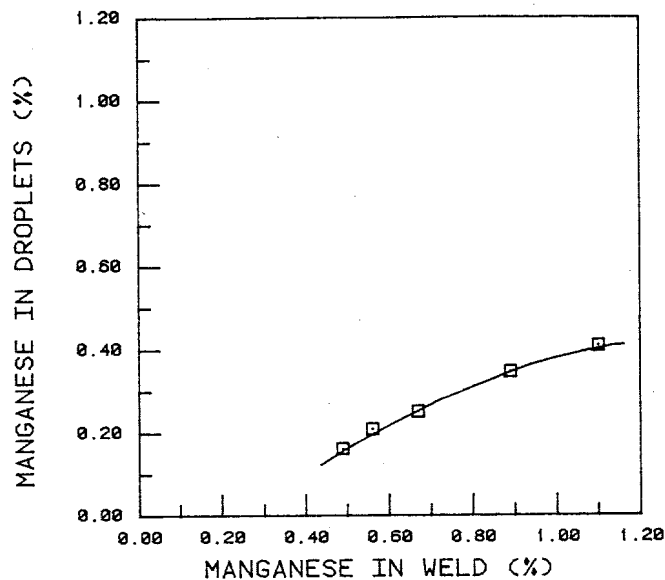


Fig. 3—Comparison of droplet composition with actual weld bead composition (multipass welding). Data from work done by North.^[9]

manganese from manganese silicate fluxes. Such empirical equations provide useful information only in the narrow range of flux-electrode combinations and under the limitations of the welding conditions from which they were derived. Application of these equations to other flux or welding conditions may lead to gross errors.^[28] Thus, any claims of generality or scientific basis for these equations cannot be accepted.

V. OXYGEN TRANSFER IN SAW

Unlike the transfer of other elements during the SAW process, researchers have not been able to determine successfully which welding process parameters affect the weld metal oxygen content. The effect of flux composition on weld metal oxygen content has been a matter of some controversy. Eagar^[31] suggested that a “basicity index” may be used to predict the oxygen content of weld metal when using silicate fluxes. Others have argued that an “oxygen potential” concept is more appropriate.^[19,29] However, unlike the basicity index, no formal definitions or formulas for oxygen potential in welding fluxes have been proposed. Neither the basicity index nor the oxygen potential concepts take into account the effect of welding parameters on oxygen content, although these parameters may change the oxygen content in the metal by as much as 300 pct.^[17]

Recent work by Lau *et al.*^[33] has provided very useful information on the sources of oxygen contamination during SAW. Their work confirms that oxygen enters the metal due to plasma-metal reactions in the arc column, as suggested by Eagar^[16] and Chai and Eagar.^[18]

VI. VERIFICATION OF PREVAILING THEORIES ON SLAG-METAL REACTIONS DURING SAW

This review of the work by previous investigators shows that the results obtained are often contradictory and that general quantitative relationships between consumable composition, process variables, and weld chemistry do not exist. At first review, the droplet theory seems to be

Table III. Chemical Composition of Electrodes Used in This Study

Electrode	Si (Pct)	Mn (Pct)	O (Pct)	Other
A-7 (1/8-in. diameter)	0.01	0.18	0.04	0.04 pct C, 0.02 pct P, 0.03 pct S
A-7 (3/32- and 1/16-in. diameters)	0.01	0.10	0.04	0.04 pct C, 0.02 pct P, 0.03 pct S
A-681	0.93	1.64	0.02	—
Ax-90	0.46	1.31	0.02	1.93 pct Ni, 0.016 pct P, 0.007 pct S, 0.4 pct Mo
A-705-3	0.54	1.20	0.02	—
Page Med-C	0.15	1.10	0.02	0.6 pct C
L-70	0.11	0.80	—	—
LD-86	0.80	1.60	—	—
LD-44	0.02	2.44	0.02	0.44 pct Mo, 0.66 pct Ni
LD-40 (1/8-in. diameter)	2.04	2.04	0.02	—
LD-80	0.03	0.45	0.04	—
LD-40 (3/32-in. diameter)	0.02	2.17	0.02	—

Table IV. Chemical Composition of Baseplates Used in This Study

Baseplate	C (Pct)	Si (Pct)	Mn (Pct)	O (Pct)	S (Pct)	P (Pct)	Other (Pct)
1008	0.02	0.001	0.35	0.04	0.008	0.010	—
1020	0.08	0.14	0.45	—	0.020	0.015	—
EZ20	9.21	0.11	1.21	0.01	0.160	0.017	—
HiSi	0.01	3.23	0.07	0.01	0.022	0.009	—
Stainless	0.08	0.47	1.64	0.01	0.007	0.022	18.4 Cr, 9.7 Ni
HiP	0.06	0.26	1.57	0.01	0.005	0.098	—
HY-80	0.16	0.22	0.26	0.01	0.012	0.011	2.17 Ni, 1.35 Cr

Table V. Chemical Composition of Fluxes Used in This Study

Flux Constituent	Fx-1	Fx-2	Fx-3	Fx-4
SiO ₂ (pct)	50	36	55	40
CaO (pct)	3	47	28	—
MgO (pct)	—	—	12	—
MnO (pct)	40	0.10	0.5	—
Al ₂ O ₃ (pct)	—	—	5	—
CaF ₂ (pct)	5	10	—	60
TiO ₂ (pct)	—	5	—	—
FeO (pct)	—	—	—	—

promising, but on more careful examination, two serious shortcomings of the droplet theory are noted:

1. In spite of the fact that several researchers had claimed this mechanism of element transfer, none of them has been able to put forward any quantitative scientific theory.
2. The droplet theory contradicted the results of early work by Christensen and Chipman^[29] on shielded metal arc welds, which indicated that the controlling step for manganese transfer between the slag and the metal occurs in the weld pool.

In view of the strong support in the literature for the droplet theory, in spite of several experiments which refuted this hypothesis, it was decided to perform some simple preliminary experiments to test the validity of the droplet theory. The compositions of the electrodes, baseplates, and fluxes used in the preliminary experiments, as well as those performed later,^[34] are listed in Tables III through V, respectively. Fluxes Fx-1, Fx-2, and Fx-3 are commercial compositions, while Fx-4 was prepared in the laboratory by induction melting in a graphite crucible. The welding equipment consisted of a Linde VI-800 power supply with a Linde EH-10 electrode feeder and a UCC-8 control.

In the first experiment, a series of welds was made using different combinations of baseplates and electrodes. The welds were made with the same manganese silicate flux and under constant welding conditions (30 V direct current electrode positive (DCEP), 400 A, 40 cm/min). The results of these experiments are shown in Table VI.

Table VII. Alloying Elements Lost to Slag on Welding with A-7 (Alloy-Free) Electrodes

Weld Metal Composition		Amount Lost
(a) Welds Made with EZ20 Baseplate and Fx-2 Flux		
Mn Nominal (Pct)	Mn Actual (Pct)	ΔMn (Pct)
0.87	0.57	-0.30
0.77	0.60	-0.17
0.76	0.53	-0.23
0.83	0.59	-0.24
0.50	0.43	-0.07
0.72	0.57	-0.15
0.67	0.40	-0.27
0.63	0.38	-0.25
(b) Welds Made with HiSi Baseplate and Fx-2 Flux		
Si Nominal (Pct)	Si Actual (Pct)	ΔSi (Pct)
2.14	2.00	-0.16
2.05	1.78	-0.27
2.05	1.74	-0.31
2.24	2.02	-0.22
2.40	2.33	-0.17
(c) Welds Made with Stainless Baseplate and Fx-1 Flux		
Cr Nominal (Pct)	Cr Actual (Pct)	ΔCr (Pct)
11.59	10.30	-1.29
12.42	10.80	-1.62
11.222	7.89	-3.33
14.90	13.10	-1.80
15.46	13.33	-2.16
15.46	13.0	-2.46
10.67	5.84	-4.83
13.06	11.4	-1.66

If reactions between the droplets and the slag account for the transfer of manganese and silicon, then weld 1-1 (Table VI), made with a 0.18 pct Mn electrode and a 1.21 pct Mn baseplate, should gain a great deal of manganese from the manganese silicate slag, whereas

Table VI. Results of Preliminary Experiments Showing Alloy Transfer Is Not Controlled by Droplet Reactions*

Weld No.	Electrode	Composition of Baseplate	Weld Metal Composition		Change in Composition due to Chemical Reaction
			Nominal**	Actual	
1-1	0.18 pct Mn	1.21 pct Mn	0.78 pct Mn	1.20 pct Mn	+0.10 pct Mn
1-2	1.20 pct Mn	1.20 pct Mn	1.20 pct Mn	1.20 pct Mn	0.0 pct Mn
1-3	2.17 pct Mn	0.35 pct Mn	1.08 pct Mn	1.15 pct Mn	+0.07 pct Mn
1-4	0.18 pct Mn	0.35 pct Mn	0.28 pct Mn	0.64 pct Mn	+0.36 pct Mn
2-1	0.93 pct Si	0.00 pct Si	0.32 pct Si	0.70 pct Si	+0.38 pct Si
2-2	0.8 pct Si	0.8 pct Si [†]	0.80 pct Si	0.85 pct Si	0.05 pct Si

*All welds made with flux Fx-1.

**Nominal weld composition = (baseplate composition) (dilution) + (electrode composition) (1 - dilution).

[†]Artificial baseplate made of electrode wire used.

Table VIII. Effect of Electrode and Baseplate Compositions on Weld Metal Oxygen Content in Multilayer Weld Bead Pads

Flux	Electrode Composition	Baseplate Composition	Layer 1 Oxygen	Layer 3 Oxygen	Layer 6 Oxygen
Fx-1	0.01 pct Si, 0.1 pct Mn	0.001 pct Si, 0.35 pct Mn	0.17	0.20	0.22
Fx-1	0.01 pct Si, 0.1 pct Mn	3.23 pct Si, 0.06 pct Mn	0.12	0.22	0.20
Fx-1	0.93 pct Si, 1.67 pct Mn	3.23 pct Si, 0.06 pct Mn	0.10	0.17	0.18
Fx-1	0.93 pct Si, 1.67 pct Mn	0.001 pct Si, 0.35 pct Mn	0.13	0.18	0.20
Fx-2	0.01 pct Si, 0.1 pct Mn	3.23 pct Si, 0.06 pct Mn	0.04	0.06	—
Fx-2	0.93 pct Si, 1.64 pct Mn	3.23 pct Si, 0.06 pct Mn	0.02	0.03	0.03

Table IX. Data Showing Transfer of Oxygen Is Independent of Transfer of Silicon and Manganese

Reference	Flux Name	Weld Number	Flux Type	Δ Mn	Δ Si	Δ O (ppm)
This study	Fx-4	Si-1	CaF ₂ -SiO ₂	—	-0.31	+ 800
This study	Fx-4	Si-3	CaF ₂ -SiO ₂	—	-0.23	+1000
8	F-2	2-6	CaO-MnO-SiO ₂ -Al ₂ O ₃	-0.36	-0.10	+ 600
8	F-2	2-3	CaO-MnO-SiO ₂ -Al ₂ O ₃	-0.36	-0.04	+ 580
8	F-2	2-16	CaO-MnO-SiO ₂ -Al ₂ O ₃	-0.40	-0.05	+ 600
8, 17	F-4	8	CaO-SiO ₂ -Al ₂ O ₃	-0.50	-0.24	+ 400
8, 17	F-4	3	CaO-SiO ₂ -Al ₂ O ₃	-0.20	-0.02	+ 360
30	7B	7B	CaO-CaF ₂ -Al ₂ O ₃	-0.52	-0.11	+ 180
30	28B	28B	CaO-CaF ₂ -Al ₂ O ₃	-0.47	-0.17	+ 180

weld 1-3, made with a 2.17 pct Mn electrode and 0.35 pct Mn baseplate, should lose a great deal of manganese to the slag. However, the experimental data (Table VI) show that the gain of manganese was similar for both welds. Also, weld 1-4, made with a 0.18 pct Mn electrode and a 0.35 pct Mn baseplate, gained much more manganese than either weld 1-1 or 1-3, since its nominal composition was much lower. If the droplet theory were correct, the baseplate composition should have no effect, and the relative gain in weld 1-4 should be the same as in weld 1-1. Similar results can be seen for Si from welds 2-1 and 2-2, indicating that slag-metal reactions occur in the weld pool after the electrode droplets mix with fused metal from the baseplates. Again, if the transfer of silicon is within the droplet, the relative gain in welds 2-1 and 2-2 should be the same.

A second experiment was performed with an electrode containing traces of alloying elements (0.01 pct Si, 0.18 pct Mn, 0.00 pct Cr) and baseplates and fluxes of different compositions, as shown in Table VII. In this experiment, the experimental parameters were varied.^[28] The data in Table VII show clearly that the weld metal loses Mn, Si, and Cr even on welding with electrodes essentially free of these elements, thus confirming that the controlling reactions occur in the weld pool. If the primary reactions occurred in the droplet, such welds could only gain Mn, Si, and Cr.

Preliminary experiments were also made to study the effect of electrode and flux compositions on oxygen transfer. In one experiment, a series of multiple-pass welds was made using different combinations of electrodes and baseplates for two different fluxes, Fx-1 and Fx-2. In these experiments, the welding constants were maintained at 30 V DCEP, 300 A, and 60 cm/min. The re-

sults of these experiments are presented in Table VIII. The results show that although flux composition has the strongest influence in determining weld metal oxygen composition, both electrode and baseplate compositions have significant influences. Also, the top (sixth) layer contains greater amounts of oxygen than the first layer for all of the welds. Also, welds were made with flux Fx-4 (60 pct CaF₂-40 pct SiO₂) with a high-silicon electrode (0.93 pct Si) and baseplate (3.23 pct Si), and it was noted that the metal could lose silicon and gain oxygen. The result of this experiment, along with other data from the literature, is presented in Table IX. The results of both Tables VIII and IX will be discussed in more detail in Parts II^[35] and III^[34] of this series.

These preliminary experiments clearly disprove claims that the alloying elements are transferred in the zone of droplet reactions. Thus, a new approach starting from first principles is necessary to investigate and explain the reactions that occur during SAW. This will be covered in Part II^[35] of this series.

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